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A Study on Automatic Navigation of Ship Using Artificial Intelligence Method

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인공지능 방법을 이용한 선박 자동 항해에 관한 연구

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〈목 차〉

요 약

인공 지능 분야에서 특히 퍼지와 같은 기술은 전반적인 산업 자동화에 많이 사용되어 왔다. 퍼지 제어는 인간의 추론 과정을 모델링한 기술로서 인간에 유사한 결정 능력과 복잡하고 다양한 환경에 매우 효과적이다. 본 논문은 이러한 퍼지 제어의 장점을 연근해의 선박 자동 항해에 적용시켜 보았다. 심해에서는 공간상의 제약이 없기 때문에 선박의 자동항해는 원하는 목표지점까지 안전하게 운항할 수 있지만, 연근해안에는 심해와 달리 각종 장애물들(작고 큰 섬들과 해안, 연근해에 작업중인 선박들)이 있으며 이것들로 인한 충돌사고가 종종 발생하고 있는 실정이다. 그러므로 연근해안에서 보다 안전하고 자율적인 항해를 위해 인공 지능 기술인 퍼지 기술을 선박에 적용시켰다. 본 논문에서 제안된 다변수 퍼지 시스템을 2개의 서로 다른 동적 환경을 가지는 지형에 적용시켜 보았고, 그에 따른 실험들을 수행했을 때, 만족할만한 결과를 얻을 수 있었다. 따라서, 본 논문에서 제안된 다변수 퍼지 제어시스템을 이용한 선박이 동적인 환경에서도 스스로 장애물을 인식하고 회피함으로 안전하게 연근해를 운항할 수 있음을 보였다.

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1. Introduction

Automation is one of the very important part modern industry societies. The research and development for an automation of various industrial machine and automatic control of dynamic plant have been studied over the last several decades[3][4]. In particular, many research for vehicle have been progressed. However, the works of automatic navigation of a ship for obstacle avoidance have been not enough. In the deep sea, this matter is not necessary because ship doesn't limit place. However, in near sea it is very important because it may collide with many other moving or working ships and many obstacle, such as an island or sucken lock. Because of this reason, there have unnecessary economy loss and need many people for safety in near sea. Therefore, to overcome above problems need exact system using intelligent control[2].

One of the more popular new technologies is "intelligent control", which is defined as the combination of control theory, operations research, and artificial intelligent. Among new technologies based on artificial intelligent, fuzzy logic is the popular area. Fuzzy control is one of field for global technological, economical, and manufacturing competitions[1]-[5]. In 1980's, fuzzy control is to be usefully applied the technological field that engineering design, intelligent control, signal filtering, pattern recognition, breakdown diagnosis, and the society field that decision making, the medical, action science, economy, society model, and the nature field that phenomena, geographical features, mode of life cycles, physics & chemical phenomenon[1]. Using technique such a fuzzy is efficient to automation of vehicle. Therefore this paper used control system that composed with fuzzy logic.

In chapter 2 the multivariable fuzzy equations for open-loop control system are presented, and some formal properties of the equations are discussed. The design of map and fuzzy ship for navigation are illustrated in chapter 3. Chapter 4 of this paper shown modeling of multi variable fuzzy control system and fuzzy algorithms. Simulation results and plotting graphs are illustrated in chapter 5. The concluding remarks are given in chapter 6.

2. Multivariable Fuzzy Control System

Recent research on the application of fuzzy set theory of the design of control systems has led to interest in the theory and description of the multivariable structure of these systems. This interest has arisen mainly due to two facts. One is that real control systems are multidimensional, and the other is that the computer implementation of physical systems requires the processing of a huge database. It is often accompanied by memory overload. The analysis and design procedures for such systems are consequently very difficult.

In this chapter modeling and analysis and composition of multivariable fuzzy control system are shown. Fuzzy system by set of fuzzy equation is described at first. Series and parallel connection of multivariable fuzzy system are described secondly. Multivariable fuzzy structure of series and parallel connection are illustrated by set of fuzzy equation and block diagram and fuzzy relations and the logic operator are used in design of multivariable fuzzy systems.

2.1 Multivariable structures of fuzzy control system

Open-loop fuzzy systems are systems in

which the outputs have no effect upon the input control actions. When described by fuzzy relations, such systems are called open-loop fuzzy systems[2,3,4].

Consider now a multivariable system shown in Fig. 1.

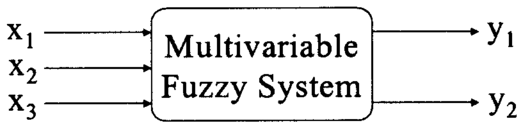


Fig. 1. Multi-input multi-output fuzzy system

Therefore, the linguistic description of the process is given by

IF $X_{1(1)}$ AND $X_{2(1)}$ AND $X_{3(1)}$ THEN $Y_{1(1)}$ AND $Y_{2(1)}$
ALSO
IF $X_{1(2)}$ AND $X_{2(2)}$ AND $X_{3(2)}$ THEN $Y_{1(2)}$ AND $Y_{2(2)}$
ALSO
.
.
.
IF $X_{1(i)}$ AND $X_{k(i)}$ AND $X_{3(i)}$ THEN $Y_{1(i)}$ AND $Y_{j(i)}$
.
.
.
ALSO
IF $X_{1(n)}$ AND $X_{2(n)}$ AND $X_{3(n)}$ THEN $Y_{1(n)}$ AND $Y_{2(n)}$
.... (1)

where $X_{k(i)}$ is the fuzzy value of the k-input variable defined in the universe of discourse X^k, k=1, 2, 3; and Y^j is the fuzzy value of the jth output variable defined in the universe of discourse Y^j j= 1, 2. To avoid such long formulate, the following abbreviation for (1) will now be used:

$$\{(\text{IF } X_{1(i)} \text{ AND } X_{k(i)} \text{ AND } X_{3(i)} \text{ THEN } Y_{1(i)} \text{ AND } Y_{j(i)}), (\text{ALSO})\},\ i = 1, 2, \cdots, n$$

Let the dimensions of the universe of discourses X^k and Y^j be, respectively,

$$\dim[X^k] = q_k,\quad \dim[Y^j] = p_j$$

The fuzzy relation R of the system is expressed as follows

$$R = \bigvee_{i=1}^{n} \{X_{1(i)}X_{2(i)}X_{3(i)}Y_{1(i)}Y_{2(i)}\} \quad \cdots\cdots (2)$$

where $\dim[R] = q_1 \times q_2 \times q_3 \times p_1 \times p_2$.

To obtain the present outputs Y_1, Y_2, given the current inputs X_1, X_2, X_3, the following compositional rule of inference[6] is used:

$$Y = X_1 \circ X_2 \circ X_3 \circ R \quad \cdots\cdots (3)$$

The result of this composition is a compound fuzzy set Y in the universe $Y_1 \times Y_2$, where $\dim[Y] = p_1 \times p_2$. The individual outputs can be calculated by the projection of the compound output fuzzy set (3) on the respective universes[7].

$$Y_1 = \bigvee_{Y_2} Y,\quad Y_2 = \bigvee_{Y_1} Y \quad \cdots\cdots (4)$$

Because of the multi-dimensionality of the relation (2) and fuzzy output (3), a straightforward analysis and synthesis of the multivariable fuzzy system is difficult to obtain. To overcome this difficulty, it is proposed, in analogy to the theory of linear systems, the following form of equations governing the three-input two-output system.

$$Y_1 = X_1 \circ R_{11} \varDelta X_2 \circ R_{21} \varDelta X_3 \circ R_{31}$$
$$Y_2 = X_1 \circ R_{12} \varDelta X_2 \circ R_{22} \varDelta X_3 \circ R_{32} \quad \cdots\cdots (5)$$

where $\mathbf{R}_{kj}$ are two-dimensional (flat) fuzzy relations, and $\varDelta$ denotes a certain rule of composition. As can be seen in (5), the formulas cannot be exact for all systems, no matter which composition $\varDelta$ is selected. Namely, R has $q_1 \cdot q_2 \cdot q_3 \cdot p_1 \cdot p_2$ elements which, in general, are independent, while all the $\mathbf{R}_{kj}$ contain only $(q_1+q_2+q_3)(p_1+p_2)$ elements. To obtain a more tractable structure, a loss of accuracy must be accepted.

The representation (5) is obtained in the following way. Starting from (2) and (3) it is found that

$$Y = \underset{X^1}{V} X_1 \wedge \underset{X^2}{V} X_2 \wedge \underset{X^3}{V} X_3$$

$$\overset{n}{\underset{i=1}{V}} \{ X_{1(i)} \wedge X_{2(i)} \wedge X_{3(i)} \wedge Y_{1(i)} \wedge Y_{2(i)} \}$$

$$= \overset{n}{\underset{i=1}{V}} \Big\{ \underset{X^1}{V} X_1 \wedge X_{1(i)} \wedge Y_{1(i)} \wedge \underset{X^2}{V} X_2 \wedge X_{2(i)} \wedge Y_{1(i)}$$

$$\wedge \underset{X^3}{V} X_3 \wedge X_{3(i)} \wedge Y_{1(i)} \wedge \underset{X^1}{V} X_1 \wedge X_{1(i)} \wedge Y_{2(i)}$$

$$\wedge \underset{X^2}{V} X_2 \wedge X_{2(i)} \wedge Y_{2(i)} \wedge \underset{X^3}{V} X_3 \wedge X_{3(i)} \wedge Y_{2(i)} \Big\} \quad \cdots (6)$$

Now define the fuzzy relation R_{kj} as

$$R_{kj} = \overset{n}{\underset{i=1}{V}} \{X_{k(i)} \wedge Y_{j(i)}\}, \quad k=1,2,3, \; j=1,2 \quad \cdots (7)$$

By taking the projection (4), the following is obtained from (6)

$$\begin{aligned} Y_1 &= X_1 \circ R_{11} \wedge X_2 \circ R_{21} \wedge X_3 \circ R_{31} \\ Y_2 &= X_1 \circ R_{12} \wedge X_2 \circ R_{22} \wedge X_3 \circ R_{32} \end{aligned} \quad \cdots (8)$$

that is, relation (5), where Δ is the conjunction operator.

It should be noted now that the six-dimensional fuzzy matrix R, and two-dimensional fuzzy output Y (see (2) and (3)) are decomposed into six two-dimensional fuzzy matrices $R_{11}, \cdots, R_{32}$, and two one-dimensional fuzzy outputs Y_1, Y_2.

Consider now the three inputs (i,e., X_1, X_2, X_3) to be the components of an input vector. Similarly, the two outputs (i.e., Y_1, Y_2) may be regarded as the components of an output vector. Using vector-matrix notation, the input-output set of fuzzy equations in (8) can be written as

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}' = [X_1 \; X_2 \; X_3] * \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \\ R_{31} & R_{32} \end{bmatrix} \quad \cdots (9)$$

where * is the ($\circ$,$\wedge$)-operator. In a compact form, (8) can be written as

$$Y_z = X_z * R_z \quad \cdots (10)$$

where

$$Y_z = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}', \quad X_z = [X_1 \; X_2 \; X_3]$$

and

$$R_z = \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \\ R_{31} & R_{32} \end{bmatrix}$$

Here Y_z is the (p_1 + p_2) output vector, X_z is the (q_1 + q_2 + q_3) input vector, and the compact fuzzy matrix R_z has (q_1 + q_2 + q_3) rows and (p_1 + p_2) columns.

Equations (8)-(10) show the relationships between the three inputs and two outputs. Although the vector-matrix equation in (10) is simple, the actual relation in terms of the decomposed matrices Rkj are quite complex as shown by (8).

To understand better the nature of the linguistic description (1) and its mathematical counterpart (8), a multivariable block diagram form is now proposed. its mathematical equivalent in (2) that the multivariable fuzzy equations of (8) consist of a number of functional blocks linked up by the intersection operators. The multivariable structure of the fuzzy system consists, therefore, of input signals, branch points, functional blocks, inner signals, intersection blocks, and output signals as shown in Fig. 2.

According to the multivariable structure of Fig. 2 the inner and output signals take the form

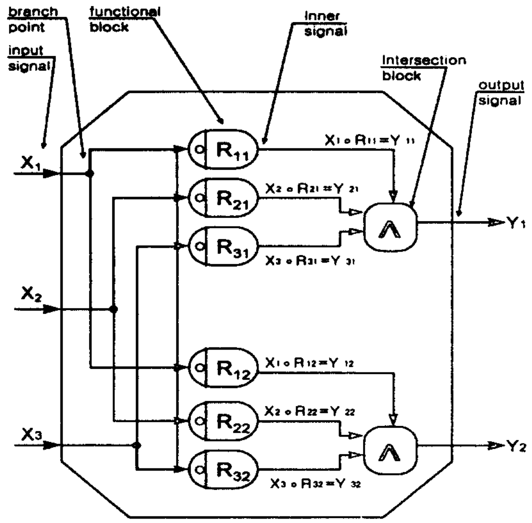


Fig. 2. Multivariable structure of fuzzy control system

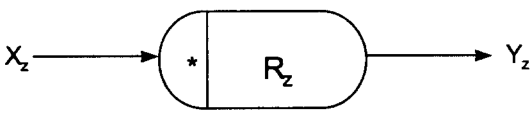


Fig. 3. Compact structure of multivariable fuzzy system

$$Y_{kj} = X_k \circ R_{kj},\ k=1,2,3,\ j=1,2 \quad \cdots\cdots (11)$$

$$Y_j = \bigwedge_{k=1}^{3} Y_{kj},\ j=1,2 \quad \cdots\cdots (12)$$

Applying the same idea to (9) and (10), a compact structure of a multivariable system as shown in Fig. 3 is obtained.

Therefore, a generalized description of the fuzzy system with M inputs and N outputs is given by

$$Y_j = \bigwedge_{k=1}^{M} X_k \circ R_{kj},\ j=1,2,\cdots,N \quad \cdots\cdots (13)$$

The multivariable structure of the system which has M inputs and N outputs contains M×N-functional blocks, M×N-inner signals Y_{kj}, M-branch points, and N-intersection blocks.

The advantages of the block diagram representation of a multivariable fuzzy system lies in the fact that it allows the overall block diagram for the entire system to be easily constructed by merely connecting the blocks of the components according to the set of fuzzy equations. It is also possible to evaluate the contribution of each component to the overall performance of the system. The functional operation of the system can be visualized more readily by examining the block diagram than by examining the linguistic system itself. A block diagram contains information concerning signals flow, but it does not contain any information concerning the physical construction of the system. Therefore, many dissimilar and unrelated fuzzy systems con be represented by the same block diagram. Hence this block diagram, which is a graphical representation of the sequence of operations, can be easily converted into a computer program to compute the response sequence. By mean of this representation, it is possible to perform any analysis and synthesis on a computer. It should be noted, however, that a block diagram of a given fuzzy system is not unique. A number of different block diagrams may be drawn for the same system, depending upon the viewpoint adopted in the analysis and synthesis. To draw a block diagram for a multivariable fuzzy system, one must write first the set of fuzzy equations based on the linguistic description which describes the fuzzy behaviour of the system. Then, one must take the decomposed fuzzy matrices and represent each fuzzy equation individually in functional block form. Finally, the elements must be assembled through branch points and intersection blocks into a complete block diagram.

2.2 Interconnections of multivariable fuzzy control system

In an industrial process a complex system can be decomposed into several interconnected subsystems based on the physical structure of the process. To avoid the computational burden due to the complexity of the global model and yet retain the coupling effects, one may wish to develop a fuzzy model, which aggregates those parts of the system that are not of immediate concern, and maintain a similar structure for the subunits under consideration. Therefore, in chapter, it is explained a parallel, and a series-parallel connection of multivariable open-loop fuzzy systems will be analyzed now.

[Series Connections]

A series of connections of two multivariable systems, as shown in Fig. 4, will be described by the following linguistics description.

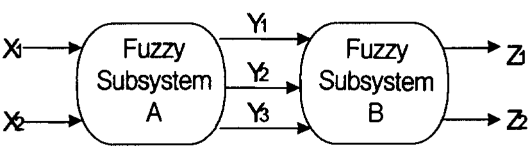


Fig. 4. Series connection of two fuzzy subsystems

Fuzzy Subsystem A :

$$\{(\text{IF } X_{1(i)} \text{ AND } X_{2(i)} \text{ THEN } Y_{1(i)} \text{ AND } Y_{2(i)} \text{ AND } Y_{3(i)}), (\text{ALSO})\},\quad i=1,2,3,\cdots,n \qquad (14)$$

Fuzzy Subsystem B :

$$\{(\text{IF } Y_{1(i)} \text{ AND } Y_{2(i)} \text{ AND } Y_{3(i)} \text{ THEN } Z_{1(i)} \text{ AND } Z_{2(i)}), (\text{ALSO})\},\quad i=1,2,3,\cdots,n \qquad (15)$$

Based on the previous considerations, a vector matrix notation of the subsystems in terms of the fuzzy equations has the following form:

Fuzzy Subsystem A :

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix}' = [X_1 \ X_2] * \begin{bmatrix} R^A_{11} & R^A_{12} & R^A_{13} \\ R^A_{21} & R^A_{22} & R^A_{23} \end{bmatrix} \qquad (16)$$

where

$$R^A_{kj} = \bigvee_{i=1}^{n} \{X_{k(i)} \wedge Y_{j(i)}\}, \quad k=1,2,3$$

Fuzzy subsystem B :

$$\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix}' = [Y_1 \ Y_2 \ Y_3] * \begin{bmatrix} R^B_{11} & R^B_{12} \\ R^B_{21} & R^B_{22} \\ R^B_{31} & R^B_{32} \end{bmatrix} \qquad (17)$$

where

$$R^B_{kj} = \bigvee_{i=1}^{n} \{Y_{k(i)} \wedge Z_{j(i)}\}, \quad k=1,2,3, \ j=1,2$$

Substituting (16) into (17), the following composite fuzzy system of two multivariable open-loop systems connected in series is obtained:

$$\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix}' = [X_1 \ X_2] * \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix} \qquad (18)$$

where

$$R_{11} = R^A_{11} \cdot R^B_{11} \wedge R^A_{12} \cdot R^B_{21} \wedge R^A_{13} \cdot R^B_{31}$$

$$R_{12} = R^A_{11} \cdot R^B_{12} \wedge R^A_{12} \cdot R^B_{22} \wedge R^A_{13} \cdot R^B_{32}$$

$$R_{21} = R^A_{21} \cdot R^B_{11} \wedge R^A_{22} \cdot R^B_{21} \wedge R^A_{23} \cdot R^B_{31}$$

$$R_{22} = R^A_{21} \cdot R^B_{12} \wedge R^A_{22} \cdot R^B_{22} \wedge R^A_{23} \cdot R^B_{32}$$

Equation (18) is represented by the structure shown in Fig. 5.

The reduced fuzzy model (18) contains the system's structural information. Using (16)-(18), a multivariable series-connected system with a given linguistic description can be analyzed or synthesized.

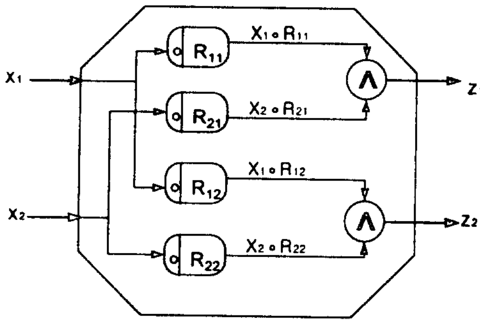


Fig. 5. Multivariable structure of series connection of two fuzzy subsystems

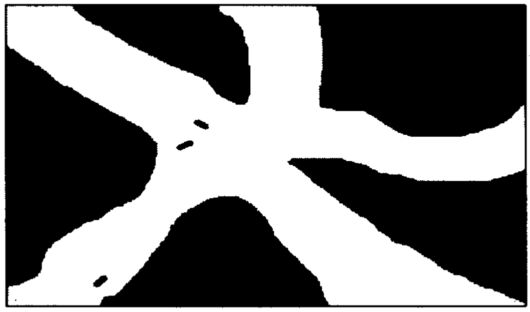
3. Design of Dynamic Environment

This chapter present a need environment for simulation. (i.e., design of map and the fuzzy ship, choice of variable numbers of input and output). Section 3. 1 illustrates the designs of two maps and the fuzzy ship to navigate the proposed map and section 3, 2 explains the variable numbers of input and output that are used to analysis of maps.

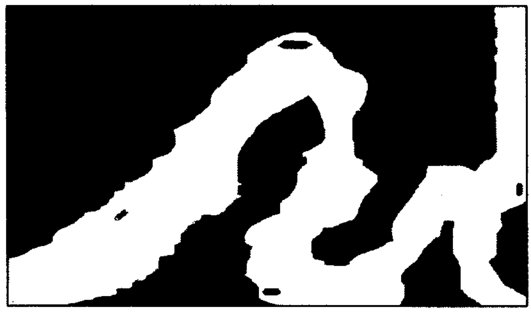
3.1 Design of map

In this paper map are designed to 640 × 480 PCX mode by NEOPAINT program which is one of many excellent graphic program. It is a convenient and simple program to draw graphic. Number of maps to simulate are four and include obstacles each other. In map static obstacles are islands and dynamic obstacles are ships which are moving or working.

Map 1 in Fig. 6 is designed to know how the fuzzy ship move various courses. The first ship which is one of three ships is designed to move from down to up of map and the second ship is designed to move straightly from the middle to the right, the third ship is designed to move from the middle to the upper left.



(a) map 1



(b) map 2

Fig. 6. Design of map

Map 2 is designed to observe how the fuzzy ship navigates a narrow course with other ships. In the map 2, the first ship is designed to navigate a similar course with the fuzzy ship at first and the second ship is designed to work until the fuzzy ship arrives at near place and finally the third ship is designed to move together the fuzzy ship at the same time.

The numerical value (i.e., width, length) of ship is generally made into a rate for the real geographic, but it may have a few errors. A kind of ship assumes not a boat but a vessel. Each coordinate is used to decide the next output of the fuzzy ship.

Fig. 7 presents points to necessary for design of the fuzzy ship. Each point(A,B,C,D,E,F) is made by the ready-selective center point of the fuzzy ship. These points are converted by trigonometrical function.

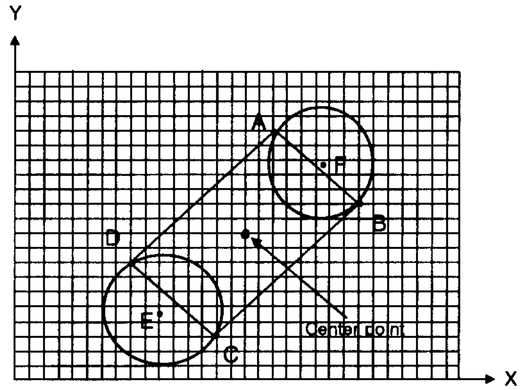


Fig. 7. Design of the fuzzy ship

3.2 Design of variable numbers of input and output

In control design of variable number of input and output is a very significant. According to their numbers, the system is complex or simple and has a good or bad efficiency[8][9]. Therefor design of variable numbers of input and output is principal. To move the fuzzy ship need variable numbers of five. Three are variable numbers of input and two are variable numbers of output parameter. The following Fig. 8 illustrates variable numbers of input and output.

In Fig. 8, DL is a distance from the fuzzy ship to the left obstacle and DM is a distance from the fuzzy ship to the front obstacle and DR is a distance from the fuzzy ship to the right obstacle. Y1 is the delta angle to decide the next direction of the fuzzy ship and Y2 is the margin to move the front ship. Y2 is used to the information to decide the next coordinates of the fuzzy ship. If the fuzzy ship is to be near place of the right obstacle (i.e., island or others ships), it turn to the left at the present place and then it move with the modified direction. If the distance of the front obstacle is long, the fuzzy ship move many distances.

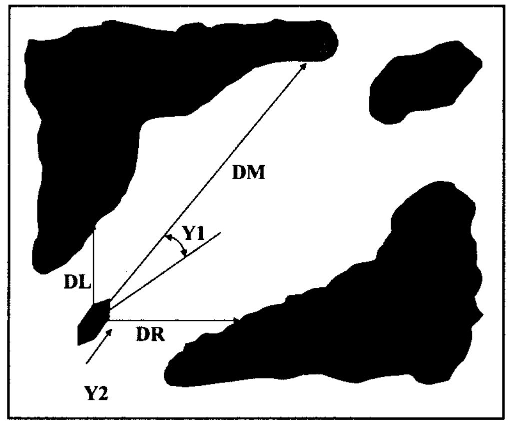


Fig. 8. Variable numbers of input and output

4. Automatic Navigation System

4.1 Modeling of multivariable fuzzy system

Fig. 9 is the block diagram of multivariable fuzzy control system. This block diagram is to express the simple connection of variable numbers of inputs and outputs.

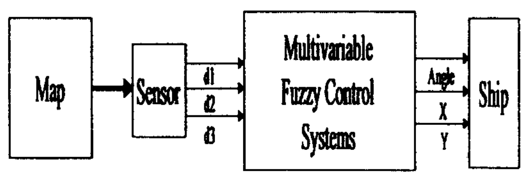


Fig. 9. Block diagram of fuzzy control systems

As shown in Fig. 8, the fuzzy ship founds distance of the left obstacle, the right obstacle and the front obstacle by three sensors.

The founded informations are transferred to input of multivariable fuzzy systems. Fig. 10 is the structure of fuzzy control system.

In Fig. 10, D1, D2, D3 is distance of each obstacle. Y1 is the delta angle of ship and Y2 is

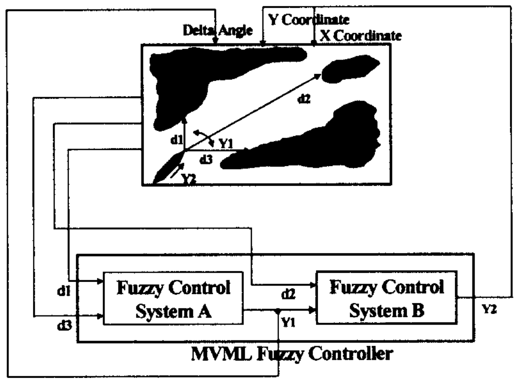


Fig. 10. Structure of the fuzzy control system

the information on x and y coordinate of the fuzzy ship. The informations collected from sensors of the fuzzy ship is used to detect the variable numbers of input and output of the fuzzy control system.

Fuzzy control system A collects a difference value of the left obstacle and the right obstacle and it is used to the variable number of input. The output of fuzzy system A modifies the angle of the fuzzy ship and it is used to one of the input variable numbers of fuzzy system B. Y1 is a half of output of the fuzzy control system A and D2 which is the distance of the front obstacle of the fuzzy ship is used to the input variable number of fuzzy control system B. The output of fuzzy system B determines the next coordinate of ship.

4.2 Fuzzy algorithm of navigation system

The need informations in navigation of ship are two that are a change of angle and distance to move the fuzzy ship. Therefore, in this paper, inputs of fuzzy control system are three and output of that is two. Fuzzy algorithms using multivariable fuzzy control system are described by the following :

[Fuzzy System A]

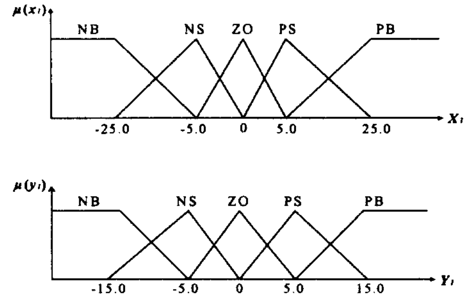


Fig. 11. Input and output membership functions of fuzzy control system A

$$X1 = D1 - D3 \quad \cdots\cdots (19)$$

Fig. 11 is to present the input and output membership function of fuzzy system which is one of the sub-fuzzy system of multivariable fuzzy system. X1 which is the input of fuzzy system A is a difference value of D1 and D3 and Y1 which is the output of that is a delta angle of the fuzzy ship.

The rules are formulated by the following verbal description.

IF X1 = NB THEN Y1 = NB
IF X1 = NS THEN Y1 = NS
IF X1 = ZO THEN Y1 = ZO
IF X1 = PS THEN Y1 = PS
IF X1 = PB THEN Y1 = PB

Where, NB = negative big, NS = negative small, ZO = zero, PS = positive small, PB = positive big.

If the fuzzy ship is near by the right obstacle, it turns to the left the present place with delta angle. In reverse, if it is near by the left obstacle, it turns to the right from the present place with delta angle. If the fuzzy ship is the middle place of the right obstacle and the left obstacle, it doesn't modify the direction of fuzzy ship. Y1 is a delta angle for navigation of the fuzzy ship and it is calculated by rules.

[Fuzzy System B]

Fuzzy control system B has two inputs(Fig. 11). One is X2 that is distance in front of ship, the other is X3 that is a half of Y1 which is the output of fuzzy system A. A delta angle is already chosen as the output of fuzzy control system A.

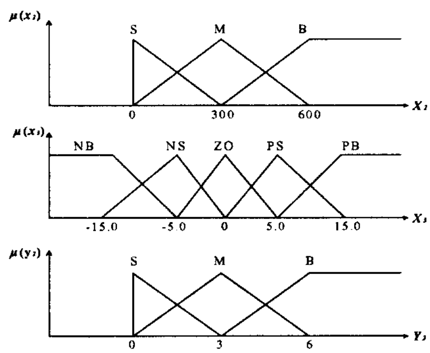


Fig. 12. the membership function of fuzzy control system

X1=dl-d3, X2=d2, X3= ‖ 0.5*Y1 ‖ .... (20)

Y1=delta angle, Y2=ship step .... (21)

The rules are described by the following verbal description :

X2 = S and X3 = ZO THEN Y2 = S
X2 = S and X3 = PS THEN Y2 = S
X2 = S and X3 = PB THEN Y2 = S
X2 = M and X3 = ZO THEN Y2 = M
X2 = M and X3 = PS THEN Y2 = M
X2 = B and X3 = PS THEN Y2 = M
X2 = B and X3 = ZO THEN Y2 = B

Where, S = small, M = medium, B = big.

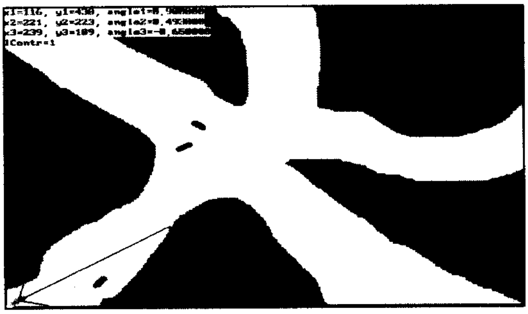
The composition method using this paper used mamdani's max-min implication. The defuzzification used the COG(Center Of Gravity) method.

5. Simulation results

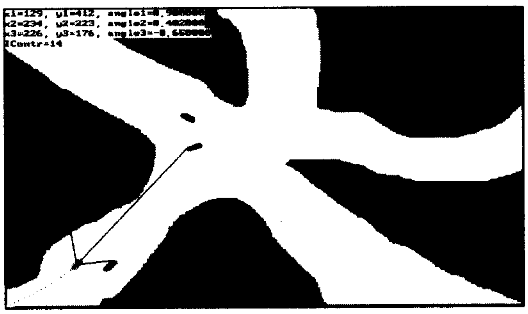
The fuzzy ship using the multivariable fuzzy control systems, navigates like the following twoe maps, Fig. 13 to 14. Each map has the result presented by four steps. Step 1 shows the initial point of each map, step 2 shows when the fuzzy ship meets the first moving obstacle. Step 3 and 4 show when the fuzzy ship meets the second and third moving obstacles respectively.

Fig. 13 illustrates the simulation results when the fuzzy ship navigates according to map 1. The purpose of this map is to know how the fuzzy ship move the simple course. As shown Fig 13, the simulation result is appeared to be successful.

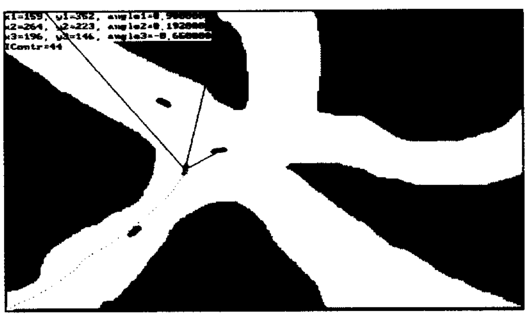
In step 1, DL is long than DR and DM shoots beam toward the right seacoast line. Therefore, the fuzzy ship moved to the left. Step 2 shows when the right sensor of the fuzzy ship meets the first obstacle. In this step, the fuzzy ship is moving to the middle of course. After that event, when it meets the new obstacle in the right side of the fuzzy ship. it immediately turns to the left. At that time, DM found other obstacle, but it isn't significant, because it is sufficient enough to avoid the obstacle. Step 3 displays when the fuzzy ship arrived at the middle of the map. Among several possible paths to move, the fuzzy ship chooses the upper left path, because the distance from the moving ship to the left obstacle is shorter to the right obstacle. In step 3, DL is longer than DR, and then the fuzzy ship moves to the left. Finally, the fuzzy ship meets with the third obstacle that is moving toward the upper left(step 4) and then it also navigates safely as the same before.



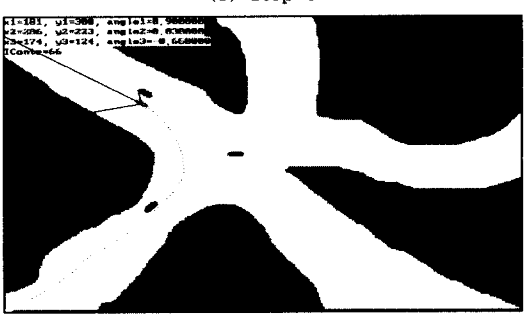
(a) step 1



(b) step 2

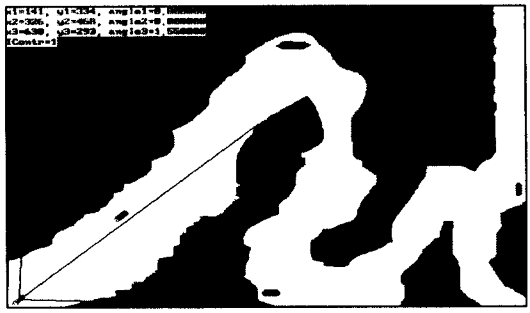


(c) step 3

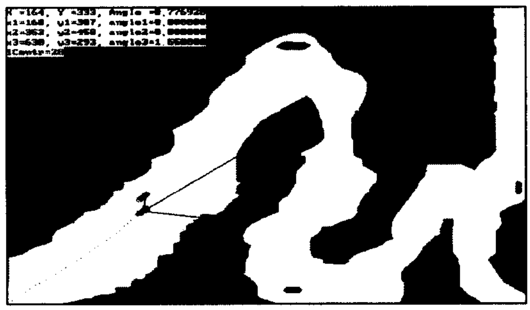


(d) step 4

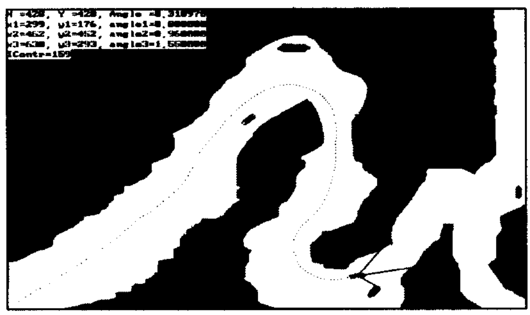
Fig. 13. Simulation result of map 1



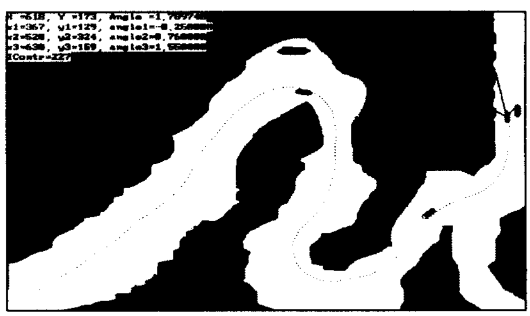
(a) step 1



(b) step 2



(c) step 3



(d) step 4

Fig. 14. Simulation result of map 2

Fig. 14 is the result when the fuzzy ship navigates map 2 and it satisfies as shown the above. Step 1 displays the starting point of the fuzzy ship and because the DL of the fuzzy ship is nearly equal to DR, the fuzzy ship moves to the middle. Step 2 shows when the fuzzy ship meets the first obstacle, which is moving the same course, and then it to avoid the obstacle move to down course. As shown step 3, the fuzzy ship meets the working ship which is the second obstacle but don't collide. Because the fuzzy ship with fuzzy control system is due to take a excellent making decision ability to avoid the obstacle. Step 4 shows when the fuzzy ship meets the third obstacle, which is moving a narrow course and it navigates without collision by the obstacle. The simulation of map 2 has a good result as the map1.

6. Conclusion

This paper proposed multivariable fuzzy control system which has a exact decision ability and control technique. The proposed multivariable fuzzy control system was used to automatic navigation of ship with dynamic environment.

As shown the results, the ship with multivariable fuzzy control system navigated the various course by itself. The proposed multivariable fuzzy control system was proved that they have a good ability in dynamic environment. Two simulations were shown good results, which were responded to a sudden obstacle. The fuzzy ship successfully navigated without collision the maps proposed in this paper. Also, the fuzzy ship had different results at map with the same geographic. This was because the dynamic environment of map differed. The plotting graphs shown by simulation result offer an analysis of the multivariable fuzzy control system.

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